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Lubrication

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the Selection and Use of Lubricants

THIS ISSUE

Determination
of
Lubricating Value

Gear Lubrication
in the
Rubber Industry



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LUBRICATING *value*



IN theory, lubrication involves the reduction of solid friction between any two moving elements by interposing a layer or film of lubricating fluid between them. Solid friction is thereby changed to fluid friction, i.e., friction as it occurs between the component particles of the lubricating film.

The degree to which such a transition of friction occurs, will depend upon the actual lubricating value of the lubricant employed. Research has indicated that commensurate with the operating conditions this may vary markedly. It will depend upon certain physico-chemical characteristics, such as:

1. Surface Tension
2. Adhesion
3. Saponification, and
4. Emulsification

A better understanding of these factors will assist in more complete attainment of effective lubrication. It is our hope that this presentation will be of particular interest to those who have to do with the actual selection and application of lubricants in industry today.

To those who care to study this subject in further detail we offer the closest cooperation of our technical service, our research laboratories and reference library.



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Determination of Lubricating Value

IN the determination of the relative lubricating ability of any petroleum product it will be essential to study certain basic physical and chemical characteristics.

Of these, viscosity, pour test and carbon residue content may be considered as of outstanding importance in connection with lubricating oils; melting point, consistency and soap content being the criteria where greases are under consideration.

There are added factors, however, which research has indicated will have a direct relationship to lubricating value and which should be understood thoroughly. These will involve surface tension, adhesion, saponification and emulsification. Their relative importance, either individually or collectively, has come about by reason of the necessity for the development of certain characteristics in the process of refining which will enable the resultant product to maintain positive and effective lubrication. As an illustration of this, let us consider the requirements of lubricants to serve in the presence of moisture or wet steam. Straight mineral oils will often be far from satisfactory, due to the washing action of the water and the relative lack of adhesiveness pertinent to such products.

In studying the action of petroleum oils in the presence of water, and those characteristics in an oil which will cause it to separate easily from water, saponification, emulsification and adhesion are particularly pertinent. Unfortunately these terms have been rather frequently misused, with the result that there is a confused impression as to their real significance, or what is more important, the relationship which exists between them and lubricating value.

While the problem as to the underlying physical and chemical forces producing the effects indicated by these terms has not as yet been completely solved, there is sufficient experimental data available, borne out by scientific observation and deduction, to give a fairly definite meaning.

THE SIGNIFICANCE OF THE TERM "OIL"

Prior to a discussion of the terms mentioned above, it will be of interest to note the accepted chemical definition of the term "oil," and the classifications into which it is divided according to Hackh, in his Chemical Dictionary. It follows: "OIL—A liquid that is not miscible with water and is generally combustible and soluble in ether.

There are three large groups of oils:

- A. Fixed oils which consist of the fatty substances of vegetable and animal organisms and contain the esters (usually glycerol esters) of fatty acids.
- B. Volatile oils or essential oils which consist of the odorous principles of vegetable organisms and contain terpenes, camphors, and related compounds.
- C. Mineral oils, or fuel oils and lubricants derived from minerals as petroleum and its products which consist of hydrocarbons."

From the viewpoint of lubrication, however, it will be sufficient to study the mineral oils, and the benefits to be derived through combination with certain types of fixed oils.

RELATION OF FATTY OILS TO LUBRICATING VALUE

Research has indicated that addition of fixed oils of an animal or vegetable nature will frequently tend to improve the lubricating value of a straight mineral lubricant. This is, in fact, the genesis of the theory upon which the production of certain types of lubricating oils is based.

On the other hand, it must be borne in mind that while the addition of a fixed oil or fatty acid may increase the apparent oiliness, it may also increase the amount of carbon deposited. This is one reason why compounded oils are not strictly adaptable to motor car internal combustion engine service or other modes of operation involving circulating lubricating systems wherein the development of abnormal amounts of carbon deposits or gummy material might impair the operation of certain of the moving parts, or tend to accumulate within the lubricating system itself. On the other hand, in the Diesel engine air compressor and certain foreign motorcycle engines, fatty oils in compound with straight mineral products have been proved highly desirable.

There are phases of operation, however, where normal temperatures will prevail, for which compounded oils have been proved highly efficient. Notable among these are the textile and machine tool industries, wherein spindle and cutting tool lubrication have been studied to a sufficient extent to prove that by the use of readily emulsifiable products not only will the lubricant be more nearly able to perform its intended function, but, by compounding certain types of textile lubricants, subsequent removal from the yarn or fabric, should the oil reach same, will be greatly facilitated.

SURFACE TENSION

The development of practicable explanations for emulsification and adhesiveness on the basis of the usually accepted physical and chemical conceptions requires primary consideration of the surface tension.

Surface tension is a characteristic which has been given but little consideration in the selection of petroleum lubricants, not with the thought that it is lacking in importance, but due to the fact that little has been known as to its direct bearing upon lubricating value. There has, however, been some extremely interesting data developed recently, coupled with a number of papers by certain eminent investigators. By virtue of the trend of the indications brought out, surface tension is regarded by some as a direct criterion as to lubricating value. It can furthermore be accurately measured with respect to water, so that the relative values for certain classes of lubricants can be

intelligently tabulated. This does not hold true, however, where metal is concerned.

In effect this will be a measure of the relative strength of the resultant oil films, where exposed to air, for in the opinion of certain authorities it will play a part both in the formation as well as the maintenance of a sufficient lubricating film between the parts to be lubricated under such conditions, variation in surface tension being regarded as causing variation in the latter, dependent, however, upon the viscosity. In other words, with higher viscosity oils of approximately the same surface tension, the relative strength of the oil films can be expected to be greater, for research has indicated that this characteristic will have a direct relationship to viscosity as well as specific gravity, although in connection with this latter the extent to which lubricating value may be predicted is questionable at this time.

It is important to remember, however, that temperature will be an influencing factor in this regard, for surface tension varies inversely with temperature just as does viscosity. It must also be remembered that the interfacial tension between the oil film and the metallic surface is of the utmost importance.

Surface Tension Defined

As mentioned later in the discussion of emulsification, at the boundary surface between two liquids, not mutually soluble, or between a liquid and gas, there apparently exists a different set of forces than are found in the interior of the liquid or gas. If a wire is immersed horizontally just below the surface of a liquid to wet it, and then if it is raised slowly, as it is drawn through the surface the liquid follows the wire just as if the surface were a membrane being stretched. The force necessary to pull the wire away from the surface can be measured on a balance, and knowing the length of the wire, this surface force of the so-called liquid membrane can be computed. This force, which is termed the surface tension, differs somewhat from that in a stretched membrane in that it is constant no matter how far the liquid is extended.

Francis and Bennett, in their paper on "The Surface Tension of Petroleum"* give a further interesting interpretation of this term, viz.: "The surface tension of any liquid is due to the cohesive action of the particles composing the liquid. These cohesive forces act in all directions below the surface and a particle in the interior of a liquid is equally attracted on all sides, but a particle in the surface layer is attracted inwards by the particles of liquid within its sphere of influence, the corresponding at-

* The Journal of Industrial and Engineering Chemistry, Vol. 14, No. 7, P. 626, The Surface Tension of Petroleum, by C. K. Francis and H. T. Bennett.

traction by the few particles in the vapor space being negligible in comparison. Hence, at the surface of every liquid there is a force, the so-called surface tension, which acts inward and causes the liquid to act as if it were covered by an elastic skin."

From a strictly chemical point of view the definition as laid down by Hackh, in his *Chemical Dictionary*, will be of interest. He terms it—"The contractile surface force of a liquid by which it tends to assume a spherical form and to present the least possible surface (e.g., the formation of a meniscus). It may also be exerted at the junction of two liquids. It is measured directly (g. per cm² or dynes), or indirectly by determining the capillarity. Increase in temperature and the addition of certain substances lowers the surface tension."

Interfacial Tension

By reason of more or less confusion as to the use of the terms surface tension and interfacial tension, and the frequent misunderstanding of their meaning, it will be well to follow the above definition of the former with Kingzett's opinion on Interfacial Tension. He states that—"An interface is the boundary surface between two phases, and, according to Reynolds, the interfacial tension between two liquids is the difference between the surface tension of the one saturated with the other and the surface tension of the other saturated with the one. The measurements are effected by the drop-weight and capillary tube methods, the former giving results 78.8 per cent of those found by the latter. The interfacial tensions of pure liquids in contact with water are constant at one temperature, and are the less the greater their mutual solubility."

It is a fundamental scientific principle that any system possessing potential energy tends to change its form or condition so that this type of energy is decreased. As the energy in a liquid surface is a function of the surface tension and the area of the surface, and as the surface tension is constant, this potential energy will be decreased by a decrease in the surface area. Thus one liquid when surrounded by another liquid or gas, unless prevented by other forces, as those of gravitation, tends to form a sphere which geometrically has the least surface for the volume contained.

Relation to Emulsification

The phenomena of surface tension, briefly described above, has been used quite generally and fairly successfully to explain emulsions, though it is apparent that other forces may be co-existent and must be considered, for the surface tension theory does not completely explain all the phenomena.

From a practical point of view, however, this can be used as a guide as to the emulsifying tendencies of products such as steam cylinder oils. In view of the fact that the size of the drops formed will vary directly as the surface tension, the value of this latter will be indicative of the actual degree to which such an oil, for example, will emulsify in the presence of water.

Gruse extends this thought to include crude oils. His observations will, therefore, be of interest, viz.:

"The surface tension of a crude oil is of some significance with regard to the ease with which emulsions are formed. The variations between different crude oils are not large, however, and it is probable that a crude oil containing colloiddally dispersed resinous and asphaltic compounds and inorganic silt is much more likely to emulsify than one free of colloidal material, but made up of hydrocarbons having a naturally low surface tension. It must, of course, be recognized that surface tension may be lowered by the absorption of colloidal matter at the interfaces, and this influence undoubtedly plays a part in the emulsion-forming influence of asphaltic compounds."

Surface Tension of Solids

The theory is advanced by others that there are forces at the surface of a solid similar to those at the surface of a liquid and there are some experiments which seem to give some credence to the theory, but these forces are not measurable and it is not believed that the study has advanced sufficiently to warrant the acceptance of this theory until further proof is advanced to establish it. Whether there are surface tension forces in the solid or not, still there certainly are forces at the surface between the liquid and solid, as exemplified by adhesion and absorption. The term adhesion is, therefore, justified until a better one is established.

Resume

In spite of the incompleteness of explanations of interfacial relations, still a few general facts stand out and need not be confused with theory:

1. The lower the surface tension between two liquids can be made, generally speaking, the more easily will they emulsify, or the slower they will separate after emulsification.
2. Substances dissolved in a liquid even to a slight degree may greatly affect its surface tension, emulsibility or adhesiveness.
3. Dissolved substances may exist in the surface layer of a liquid to a greater or less concentration than in the main body of the liquid. This action takes place

* *Chemical Encyclopaedia*, by C. T. Kingzett, P. 385.

* *Petroleum and Its Products*, P. 75, by W. A. Gruse, Ph.D.

normally in such manner as to reduce the surface tension of the liquid and hence its surface energy. This concentration may go so far as to form a solid film on the surface, or to the contrary the surface may show practically no trace of the dissolved substance.

4. When a drop of one liquid is poured gently on the surface of another liquid in some cases it will spread out quickly in a thin layer while if another liquid is used the drop may stay suspended on the surface and have a spherical form. This spreading out is due to the fact that by such action the total surface energy is reduced, that is, the surface tension between the two liquids plus the tension between the top liquid and air is less than that between the original liquid and air. If an increase in surface energy would result from spreading, the drop will remain in spherical form.
5. At a liquid-solid surface there may be such an increased concentration of dissolved material in the surface of the liquid that by continually passing the liquid over the solid the dissolved substance (solute) will be practically removed from the solution, due to adhesion to the solid of this liquid surface layer of increased concentration. This is what happens when oils are passed through filtering substances, as fuller's earth, or charcoal. It should not be regarded, however, that this is due entirely to surface tension phenomena as many other forces may be acting simultaneously, and experimental work thus far performed has not been of sufficiently definite character as to give an entirely satisfactory explanation.

ADHESION

Adhesion, in turn, involves the forces which react between liquids and solids. As in the case of an emulsion of two liquids mutually insoluble or at most only slightly soluble, there are certain interfacial forces operating at the dividing surfaces. Between a solid and a liquid the action of these interfacial forces depends upon the composition and physical condition of the two substances. As an example, if mercury is brought in contact with glass under ordinary conditions there is apparently no attraction between the two and the glass is not "wetted" by the mercury.

There is, however, a certain degree of attraction between the two and it has been actually measured in units of force, but this attraction is less than that existing between the different mercury particles and none of the mercury adheres to the glass. If, however, mercury comes

in contact with gold and some other metals the attraction between the two metals is greater than the forces between the mercury particles, and the gold is wetted by the mercury. *This force drawing a liquid to a solid is called adhesion.*

If oil comes in contact with glass, the latter is wetted showing that the attracting forces between glass and oil are greater than those between the oil particles. Similarly there is strong adhesion between water and glass. In turn, if glass is wetted with an oil and then immersed in water, sometimes the water will replace the oil film on the glass, but at other times the oil will not be dislodged, depending on the nature of oil or what may be dissolved in it or the water.

This same action is also true of steel. When wetted with certain oils it will lose its oily coating entirely when subjected to water, especially if warm, while other oils will not be displaced and the water will drain off leaving the steel wet with oil.

Some minerals, as certain sulphides, will become coated with oil when treated with an emulsion of particular oils and water, while other minerals will only take on a water coating. This differentiation is one of the principal features underlying the flotation method of concentrating ore. The sulphides wet with oil and supported by bubbles formed in the process, can be made to float away from the rock and gangue, which is only wet with water.

It is thus seen that adhesion varies considerably between different liquids and solids, depending upon the composition, nature or impurities in the two substances, or more particularly in the interfacial surface between the two substances.

No general satisfactory method has been devised for measuring the adhesion between a liquid and a solid, especially if it is stronger than the cohesion of the liquid, though measurements have been made, where the forces of adhesion are weaker than those of cohesion, that are claimed to show the magnitude of adhesive forces. On account of this lack of actual experimental measurements the study of adhesive forces and their relation to lubrication has been greatly retarded and their explanation has been more a matter of deductive reasoning from assumed hypotheses than is desirable for practical application.

On the whole, however, lubrication may be said to be contingent upon "wetness." In other words, the extent to which a lubricating oil actually wets the surfaces of any two parts in motion with respect to one another will be a measure of the degree of lubrication which can be expected. "Wetness," however, must be understood as a distinct function of adhesion.

SAPONIFICATION

One of the essential differences between fixed or fatty oils and mineral oils involves the ability or susceptibility of the former to undergo a simple chemical reaction whereby the original compounds are split up and their elements recombined chemically, generally with certain of the alkali group. Combinations of the larger portion of the oil molecules with a metal in this manner are termed soaps, and the chemical reaction is called saponification.

In general the more common soaps are produced by treatment of a fatty oil with caustic soda or potash. On the other hand, in the preparation of certain types of lubricants it is also practicable to employ soaps containing lime or calcium, aluminum or lead.

It has already been stated that saponification is a characteristic foreign to petroleum or mineral oils. It should be understood, however, that, dependent upon the source of these latter, there may be a very slight tendency toward this phenomenon. In general, however, soaps are produced directly from fixed oils or fats.

On the other hand, the chemistry of petroleum has indicated that the same result may be obtained by the action of an alkali upon a fatty acid. *The term saponification, therefore, may be applied to the action of an alkali upon those acids of an organic nature which may be produced in a slight degree in mineral oils.*

Significance of the Saponification Number

Advantage has been taken of this property of fatty oils to produce soaps, in the development of means of determining the presence of such an oil and its approximate volume in a mixture of mineral and fatty oils. The test is commonly known as the determination of the saponification number.

Most fixed or fatty oils will react with caustic soda or potash to approximately the same degree. In other words, the equivalent amounts of the former will neutralize the alkalinity of about the same amount of caustic. In order to express this effect in a comparative manner the unit has been taken as the number of milligrams of caustic potash that will react with or be neutralized by one gram of oil. This is called its saponification number.

The saponification number of most fixed or fatty oils will range between 190 and 200. As a result, where an unknown product or lubricant is involved, by determining its saponification number a fair approximation can be made as to the amount of fatty oil contained. If the nature of this fatty oil is indicated by other tests the percentage can be determined more exactly, inasmuch as the saponification numbers of the various pure fixed oils employed by the petroleum industry are definitely known. In the

opinion of certain authorities the saponification number is of real value as an indicator of the suitability of a lubricant.

It is obvious that the determination of the saponifying ability of certain of the constituents of a lubricant may be of aid, particularly where certain requirements may be involved during operation. As mentioned above, this characteristic, together with emulsibility, must be thoroughly understood when lubricants are selected for use in the presence of water. It is well to add, however, that this will not apply without modification, to either oils or greases. In other words, where grease is involved the nature of the soap must be given consideration.

In the presence of any appreciable amount of water the relative solubility of the soap may prove a detriment to lubrication, viz.: should a soda soap grease be employed, by reason of the solubility of this type of soap, the nature of the grease might be affected by the development of an abnormal amount of emulsion which might clog the bearing oil ways. Bearing construction would, of course, be the influencing factor in this regard. In other words, should the construction of the housing be sufficiently watertight to prevent undue entry of water, the alteration of the character of the grease would be obviated.

EMULSIFICATION

In practical operation the emulsification characteristic in connection with lubricants is of distinct importance, especially where presence of water necessitates a lubricating film of greater tenacity than is obtainable by use of a straight mineral oil.

In general, this is developed by compounding with a fixed oil. What actually occurs in operation can be best understood by assuming that a well refined mineral oil is shaken up with water in a bottle, and then allowed to stand and settle for a few seconds. It will be noted that the respective liquids will separate, with a sharp surface of demarcation and that each will be comparatively clear. If, however, certain fixed oils or soaps are added to the mineral oil and the subsequent compound similarly agitated with water the two liquids will separate slower, or they may remain mixed for an indefinite period. *This intimate mixture of oil, or an oil compound, plus water is termed an emulsion.*

In petroleum parlance this term is defined as a very intimate mixture of two liquids which are insoluble or only slightly soluble in each other, the mixture being so stable and the liquids so mutually held in suspension that separation due to differences in specific gravity or density is very slow. While this definition covers the usual conception of emulsification in

the oil industry it is somewhat broader than will be used in scientific discussions.

When one considers, however, that there are practically no limiting conditions which will definitely determine whether or not we have a complete emulsion, as the transition from a solution to an emulsion is not sharp, it can be realized that we may have an emulsion and yet the combination of the two liquids may appear clear and apparently be a true solution.

On the other hand, dependent on the nature of the emulsifying liquids, there may be such a mutual action that the combination may apparently be a solid. This has led some scientists to divide what we have classified as emulsions into two groups: suspensoids and emulsoids.

Suspensoids and Emulsoids Defined

Suspensoids may be said to include any cases where one liquid is suspended in another and yet the combination of the two has practically the same viscosity and other physical characteristics as the suspending liquid or, as the physicist would term it, the dispersion medium. On the other hand, where the suspended liquid or disperse phase changes the characteristics of the dispersion medium to a marked degree the combination is known as an emulsoid.

This change of characteristics is well illustrated by the action of a soluble oil and water. Water will suspend a considerable quantity of soluble oil without appreciably changing its viscosity. Ultimately, however, there comes a point when the addition of oil to the combination tends to increase the apparent viscosity very rapidly.

Conversely, water may be added in small quantities to the oil, and not change its viscosity to any marked degree but the change is more rapid in this case than when oil is added to water, and the combination reaches the solid consistency with comparatively small quantities of water added to oil.

Causes of Emulsion

While the study of the causes of emulsification are relatively incomplete and while there are many characteristics yet to be satisfactorily and completely explained according to the usually accepted theories of physical and chemical science, still great progress has been made and sufficient experimental data has been accumulated to allow us to predict results with a fair degree of accuracy. The most generally accepted theory is that there is a balancing of physical and perhaps chemical forces at the surfaces between the two compounds, in this case liquids, so that there is no resulting tendency for the individual drops to coalesce on the one hand or to become further subdivided on the other.

These forces are sufficient to prevent or at least so retard the action of gravity from separating liquids of different density so that they remain in more or less permanent emulsion. There are some liquids, such as soluble oil, which will emulsify with greater rapidity, the particles reaching their final balanced state of subdivision very quickly, while others must be mechanically or otherwise atomized before they remain permanently in suspension.

In some emulsions the particles are so small that they can only be observed under an ultramicroscope. When thus seen they are found to be in constant rapid motion, the smaller particles being most active. This is called *Brownian movement*. In some cases the particles are so fine that they cannot be seen by the ultramicroscope and are only believed to exist by reason of the fact that a beam of light is scattered in passing through a solution or liquid combination containing these particles. This scattering of a light beam, called *Tyndal effect*, is generally taken as indicating the dividing line between a true, molecular, solution and an emulsion, or colloidal solution.

Relation of Emulsification to Practical Lubrication

Whether or not an emulsion will be essential to effective lubrication will depend upon the nature of the service, as already indicated. As stated, under water conditions it will be necessary; elsewhere, however, it must be guarded against. This will hold true especially in connection with steam turbine lubrication, where it will be of vital importance in view of the fact that wherever oxidation and emulsification may prevail to any extent impaired lubrication may result.

In fact, oxidation is in general the forerunner of sludge formation and emulsification, which latter, in turn, may ultimately lead to oil-ways and other parts of the lubricating system becoming clogged.

Sludge, in particular, must be given careful consideration. Today it is understood as comprising those insoluble or readily oxidized components in petroleum lubricants which are thrown down in the form of gummy accumulations. It is not necessarily the result of water contamination.

Emulsibility is determined in the laboratory by simulating the extent to which agitation of a lubricant may occur in actual operation, and then noting the readiness with which separation of the resultant oil-water emulsion will occur. The object, of course, is to study the emulsifying tendency of the oil. There is, therefore, a distinct relation between emulsification, or the rate at which an emulsion will develop when an oil is agitated with water, and

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demulsibility, or the rate at which this emulsion will subsequently precipitate itself or settle out.

Wherever water may gain entry into a turbine lubricating system the possibility of emulsification and the subsequent demulsibility must be given the most careful attention, not only when making initial selection and purchase of a lubricating oil, but also in its subsequent usage.

Degree of Refinement Important

Demulsibility, or the rate at which an oil will clarify itself of emulsified matter, and the completeness of this reaction will depend upon the degree and manner of refinement employed and the purpose in view. The rate of demulsibility will often be indicative of oxidizing and sludge forming tendencies, though not necessarily so. In fact often, with new oils showing the same demulsibility, practical tests indicate quite a difference in demulsibility after the oils have been used for some time.

It is well to remember that with heavier or more viscous oils emulsified matter will settle out more slowly than from more fluid products or those of lighter body. This will be especially true where the same conditions of refinement hold true.

This is one reason why a turbine oil should be of comparatively low viscosity, commensurate with other conditions, such as the operating temperature of the bearings, the gallonage capacity of the lubricating system, the period of rest and the means provided for separation of non-lubricating foreign matter. Furthermore, with lower viscosity oils, the operating temperature will be lower and the tendency towards oxidating reduced.

Method of Test

The method of determining the relative emulsifying tendencies of lubricating oils at 130 degrees Fahr., as outlined in Bureau of Mines Technical Paper 323-B will be of interest, viz.:

Apparatus

1. A 100 c.c. graduated cylinder, 1-1/16 to 1-1/8 inches inside diameter.
2. An oil or water bath for maintaining the contents of the cylinder at the specified temperature. The line of the bath liquid shall not be lower than the 85 c.c. mark on the graduated cylinder.
3. A paddle consisting of a copper plate 4 3/4 inches long, between 3/4 and 7/8 inch wide, and 1/16 inch thick.
4. Means for revolving this paddle about a vertical axis parallel to and midway between its longer edges and for keep-

ing the speed fairly constant at 1,500 r.p.m.

5. A stop so arranged that when the paddle is lowered into the cylinder the distance from the bottom of the paddle to the bottom of the cylinder will be about one-fourth inch.

Procedure

6. Place 40 c.c. of the emulsifying liquid in the 100 c.c. graduated cylinder and add 40 c.c. of the oil to be tested.
7. Heat the cylinder by means of the bath to 130 degrees Fahrenheit.
8. Stir by rotating the paddle for five minutes at a speed of 1,500 r.p.m., stop the paddle, withdraw from the cylinder and wipe clean, returning to the cylinder as much of the emulsion as possible.
9. Allow the cylinder to stand at 130 degrees Fahrenheit for the specified time and then inspect. No continuous layer of emulsion shall remain.

In addition, there is the demulsibility test which employs the same apparatus as above, but which uses different quantities of oil and measures the maximum rate of separation instead of the time. The A. S. T. M. steam emulsion (S. E.) test is also used. It is a recent development, and depends upon the action of steam for emulsifying the oil, measuring the total time of separation.

EFFECT OF OXIDATION AND CARBON DEPOSITS

The extent to which the term oiliness is referred to today in discussing all matters pertaining to lubrication, warrants a better understanding of what this term really comprises, and the relation it may have to other physical characteristics in a lubricant.

There are a wide variety of opinions in regard to the meaning of oiliness and the degree to which it can be accurately determined in any particular product. It is not within the province of this study to agree or disagree with the authorities who have discussed this characteristic. It is fitting, however, to study the relation which oiliness may have to oxidation, carbon deposits, and also its relation to surface tension. It is sufficient to say that all these are to an extent influenced by the manner of refining.

For example, filtration is known to lower the carbon forming tendencies of many lubricating oils. In view of the fact that filtration involves an added step in refinement it is evident that by increasing the degree of refinement the lubricating ability will be increased. Especially as the removal of those components which are apt

to oxidize and cause emulsification, will extend the life and durability of the oil.

It is important to remember, however, that other properties, in a lubricating oil especially, may be more important, for certain types of service, than this illusive characteristic known as oiliness. For example, in internal combustion engine service accumulations of carbon may be decidedly detrimental. In the Diesel type of engine they may lead to improper functioning of the piston rings, and the lowering of engine efficiency. In the automotive engine they may cause fouling of the spark plugs, and knocking. In the steam turbine the development of carbon deposits may lead to more ready oxidation, should the oil be called upon to function under high temperatures and in the presence of a certain amount of water. In phases of operation such as the above, however, it must be borne in mind that flood lubrication is continually maintained. In other words, volume is depended upon to take the place of actual lubricating ability, which would otherwise be essential were the bearings to be supplied with only the theoretical amount of oil needed to maintain the necessary lubricating film.

It is obvious, therefore, that under conditions of this sort the matter of oiliness, can be regarded as of secondary consideration. It is more important to develop a product which, through refinement, will meet other conditions of operation and resist oxidation more effectively, and especially the resultant effects such as thickening of the oil, formation of sludge and development of free fatty acids.

SUMMARY

We have indicated above the usual understanding of the terms surface tension, saponification, emulsion and adhesion and incidentally their relationship has become apparent. In final, it is essential to discuss how these terms are often confused. In causing the formation of emulsions, soaps have been found to be very efficient. Whether this can be explained entirely as a reduction of interfacial surface tension or whether there is a soap film formed between the globules of oil and water which prevents them from coalescing or not, is still a disputed question. Perhaps both conditions prevail along with electrical forces. Nevertheless, soaps, whether added as such, or subsequently formed in the oil or mixture, do assist emulsification, justifiably, therefore, the apparent cause of the emulsion—saponification—

is often confused with the effect—emulsification.

Similarly due either to the tendency of the soaps, fatty acids or compounds added to an oil to cause it to emulsify, their adhesion is often greatly improved and hence an emulsion is sometimes demanded in order to produce greater adhesion of the oil to a metallic surface.

That this is not essential is shown by the fact that compounds can be added to mineral oils that cause them to stick to metal gears even when running under heavy load and with water flowing over them, and yet the lubricants have no soap in them and no evidence of emulsion is apparent. If there is any emulsion at all it prevails only at the interfacial surface.

Perhaps the best practical examples of emulsification are presented by soluble oils. Soaps are generally used in their preparation, but they are more of a convenience than a necessity, as emulsification can be produced by adding correct proportions of such components as alcohol, acetone and certain fatty acids or oils.

In the case of greases which are emulsions in which the oil is held, practically speaking, by a net work to prevent it from flowing, soap is found most practical to use, though greases could be formed by mixtures of other substances. The actual structure of greases is not fully understood and in most cases the production of a good or poor grease depends largely upon the skill which the grease maker has attained through experience.

A confusion of terms also often exists among marine engineers in regard to the action of marine engine oil. In order to cause the oil to stick to the guides, piston rods, etc., a small amount of fatty oil is added to the base of mineral oil. This causes an emulsion with the condensed steam and the amount of water being small the oil becomes pasty, adhering to the metal and resisting the washing action of the water. Many an engineer calls this action saponification, yet there is absolutely no soap used or formed.

Many other examples could be given but it is believed that enough has been said to indicate the distinction between the terms referred to above. It is regretted that due to the incompleteness of the study of the action at interfacial surfaces we cannot give a more comprehensive idea of the cause of such phenomena as we see in liquid-liquid mixtures, or between liquids and solids.

Gear Lubrication in the Rubber Industry

The rubber industry as it exists today is relatively still in its infancy as compared with the many other industries of equal size and importance in the manufacturing world. Its development, however, has been probably one of the most rapid and remarkable examples of modern engineering skill and ingenuity, whereby a series of processes were perfected to turn out a supply of finished materials to satisfy a world-wide demand that grew to enormity in a surprisingly short time. Of these the automobile tire is a typical instance. Unfortunately, however, in the perfecting of rubber machinery to improve the quality of output, speed up production or manufacture new appliances, lubrication requirements have oftentimes been given but little consideration, and yet, the benefit of these improvements may be decidedly reduced unless the equipment is properly lubricated.

Gearing is without a doubt one of the most important features we have to deal with in the lubrication of rubber machinery. In general, while the variety of special processes involves considerable difference in types of machines, essentially the basic principles of the most commonly used apparatus are those of the rolling mill. According to the function they perform there are usually a number of such mills, i.e., the Crackers, wherein the crude rubber is cracked between cross spiralled rollers; the washer, which takes the cracked rubber sheet to subject it to further purification by less severe treatment between single spiralled or grooved rollers; the mixing mill, frequently of the Banbury type, whereon a thorough and intimate kneading and mixing of the rubber with the desired compounds is performed by rolling between variable speed steam heated rolls; the warming mills which heat the stock preparatory to delivery to the calenders or tubers; the refiners, and the calenders, which treat fabrics with rubber applications for articles such as tires, mechanical goods, shoes, coated fabrics, etc. While each of these machines performs a different function in the process of manufacture, and is operated under different conditions of temperature and cleanliness, gear lubrication is essentially one of the most involved operating problems.

Before discussing the matter of lubrication in detail, certain data relative to the above equipment will be of interest. As a general rule the rolls of these machines are driven at a comparatively slow speed, on the principle of the household wash wringer, through a set of reduction gearing. The speed, however, will

depend on the gear ratio. This will usually vary from 1 to 1 up to 2 to 1. This latter prevails in refiners, wherein the front rolls run slower. Some roll shafts may be fitted with additional gears to develop multiple operation. In size the mills most commonly used have rolls ranging from 16" to 26" in diameter, and 40" to 84" in length of face. In calenders, however, the usual range will be 16" to 30" diameter, with a length of face from 28" to 84". The power required to drive such mills ranges from below 50 up to 200 H.P.

Selection of the Lubricant

In view of the above it can be easily appreciated that the management should at all times be greatly interested in securing a gear lubricant that will not damage the product in any stage of its treatment. To insure this an entirely homogeneous, straight mineral lubricant should be selected which is not capable of being affected by acids, or alkalis. Furthermore, it should contain no filler such as rosin, talc, tallow, etc., and it should not harden, separate, gum, dry, crack or disintegrate under exposure to the weather. A gear lubricant of the above characteristics will possess a natural tendency to cling tenaciously to the gear teeth, thus increasing the economy to a marked extent. This adhering ability will of itself guarantee longer life to the gears by effectively protecting the teeth against wear.

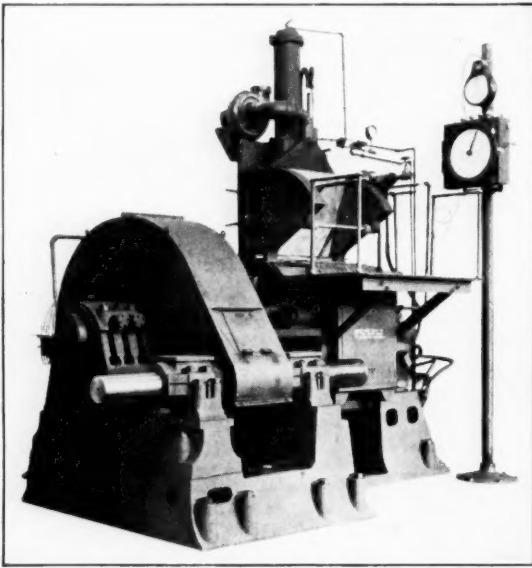
Exacting Conditions that May be Prevalent

Normally there will be two adverse operating conditions that the gear lubricant may encounter, i.e., the presence of considerable dust from the compounds, where housings are not entirely dust-tight, and the excessively heavy pressures that are customary on certain of the mills, such as the mixers. Where dust must be counteracted care should be taken to see that the gear lubricant is light enough to absorb considerable of this before it rolls up into balls and throws off; yet it must be heavy enough to continuously withstand the bearing pressures on the teeth.

Except where bath lubrication is provided for, re-lubrication at weekly intervals will normally be customary, but where the gears are unguarded and dust is especially excessive, this period should be decreased somewhat. It must be remembered that a lighter grade of lubricant will last longer and yield better results under such conditions. The heavier grade that would be used under clean operation cannot be ex-

pected to maintain an efficient lubricating film under dirty conditions, as are sometimes found, for example, around the mixers.

Where heavy bearing pressures exist, these will be transmitted to the gear teeth to some



Courtesy of Farrel-Birmingham Co.

Fig. 1—Showing a Banbury mixer, arranged for individual motor drive. The drive and connecting gears in this machine are enclosed in sheet metal oil-tight, dust-proof guards, and lubricated by oil bath. The pinion shaft bearings are flood lubricated; the main bearings are grease lubricated. Other bearing surfaces are supplied with oil from a McCord force feed lubricator.

extent. Adjusting screws are usually fitted to regulate the pressure to suit the work; therefore decidedly varying duty may be demanded of the reduction and driving gears. Due to the customary slow speeds on all but the driving pinion, the possibility of overheating or throwing of the lubricant is reduced, yet wear may be appreciable if a proper film does not coat the teeth completely.

Methods of Lubrication

Bath lubrication is usually the practice on modern rubber mill gearing, although in some older installations open lubrication may be necessary due to the exposed nature of the gears. In general, from a lubrication point of view, such gears may be regarded from five angles:

1. Where an enclosed bath enables gear lubrication apart from bearing lubrication.
2. Where there is an enclosed bath open to bearing lubricant.
3. Where gearing is so exposed as to permit only hand lubrication.
4. Where gears are exposed, but where there is provision for bath lubrication.

5. Where gearing is open and exposed to abnormally dirty operating conditions.

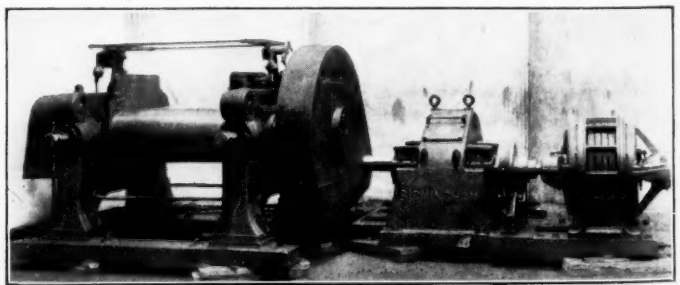
A heavy duty gear lubricant will be found admirable on all these arrangements with the exception of perhaps No. 2, where the oil from the shaft journals may pass into the bath of gear lubricant. If this occurs to any extent, considerable dilution will take place, which will reduce lubrication efficiency markedly, with the ultimate probability of excessive wear on the gear teeth. In addition a certain amount of the gear lubricant will be almost certain to leak into the bearings and cause abnormal wear and overheating. Under such a condition best practice is to observe regular routine for cleaning and renewal of the lubricant, using perhaps a somewhat heavier product than for normal bath lubrication, keeping the level as low as practicable.

Application of the Lubricant

While the type of lubricant is very essential in the obtaining of proper gear lubrication, on the other hand the actual application is of almost equal importance. Where pans are furnished for bath lubrication, they should be cleaned out at regular intervals, since any dust that may have gained entry will destroy the adhesiveness of the gear lubricant, tending to form a solid pasty mass which the gears cannot pick up.

Where the gears dip in a bath of lubricant this bath should be just deep enough so that the lowest teeth are just covered. This will give ample lubrication and keep the consumption of the lubricant at a minimum.

When the lubricant is applied by hand, it should be slightly heated to reduce it to the consistency desired, and painted on with a short



Courtesy of Farrel-Birmingham Co.

Fig. 2—Side view of a 20 in. x 48 in. rubber mill, driven by a 100 h.p. motor through an enclosed herringbone reduction gear set and cut spur drive gears. The reduction elements are bath lubricated, the bearings being flood lubricated by the same oil. The drive and connecting gears are enclosed in oil-tight, dust-proof guards and are bath lubricated. The journal bearings are grease lubricated.

brush, or poured on from a dipper as the gears are slowly revolved towards each other. Preferably pouring the lubricant on in a fine stream is the easiest, most economical and most effective method and is advised wherever possible.

LUBRICATION

Gear lubricants should be applied to open gearing in small quantities and relatively frequently, rather than in considerable volume and at longer intervals. Thus there will be less danger of gobs of lubricant being thrown off by centrifugal force, to contaminate the products under treatment.

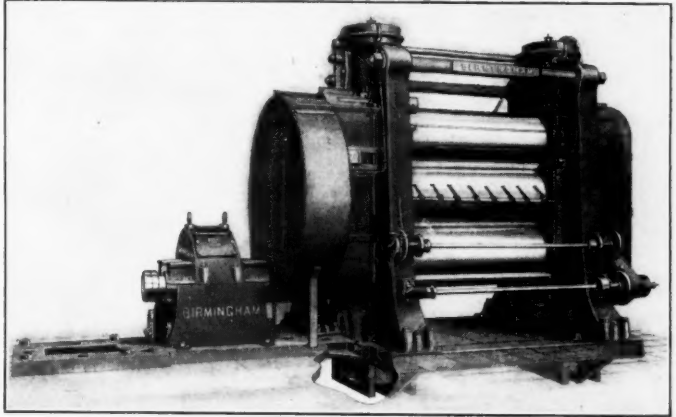
In case the lubricant becomes laden with talc, or any other dust at the root of the gears or between the gear and shield, and begins to cake, this cake can be softened and removed by the use of kerosine or naphtha.

Gear Housing an Adjunct to Effective Lubrication

The necessity of keeping gear teeth enclosed wherever possible in comparatively oil-tight and dust-tight housings is of paramount importance in the interests of effective lubrication and the minimum of wear, as has been realized by the manufacturers of modern rubber mill machinery. They have appreciated that the most essential characteristics of a good gear lubricant are that it shall have a high degree of adhesiveness and considerable body or viscosity, in order to resist effectively the throwing-off action of centrifugal force. These very characteristics, however, also

the lubricating ability of a gear lubricant, converting it into more or less of an abrasive paste, according to the hardness and the extent of the foreign matter involved.

To prevent such contamination, gears,



Courtesy of Farrel-Birmingham Co.

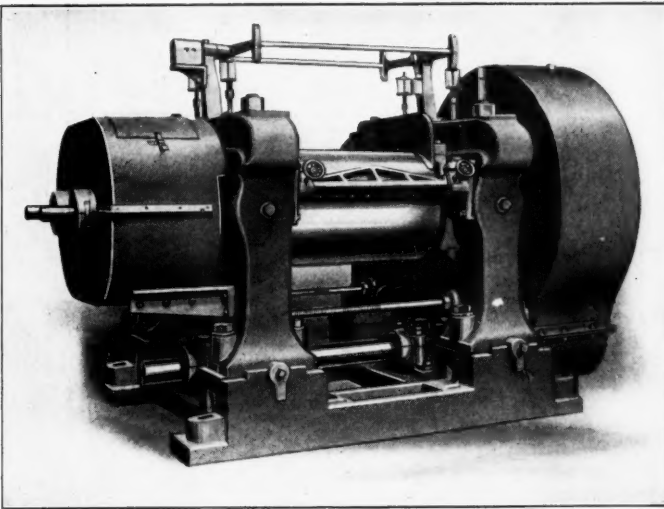
Fig. 4—Showing a three roll tire calender, driven by a 100 h.p. motor through an enclosed herringbone gear reduction. All gears on this unit are properly enclosed in dust-proof and oil-tight housings, and are bath lubricated. The reduction gear bearings are also lubricated by the same oil. The roll journal bearings, however, are supplied with oil by a McCord force feed lubricator.

wherever possible, should be adequately protected by suitable casings. Furthermore, the fact that many gear installations will function more effectively and with less consumption of power if lubricated by a relatively fluid product, renders it all the more advisable to use oil-tight casings. Especially is this true in the case of worm and herringbone gear installations; for this reason such designs are usually enclosed in very carefully planned housings which not only prevent entry of foreign matter, but also any leakage of lubricant.

For reasons of economy or practicability, however, many spur, bevel or other type of gear drives cannot be so tightly enclosed. Many operators of older machinery in the face of such conditions will, with a lack of appreciation of the serious potential consequences, such as wear, power losses, noise or personal hazard, neglect to use any but the flimsiest kind of guards. Perhaps they may even allow such gears to operate absolutely open. On a gear driven tractor or steam traction engine, for example, this may

be necessary, but on rubber mill machinery it is usually unwarranted.

Gears which operate exposed either entirely or in part must, normally, be lubricated by lubricants of heavier body or viscosity than



Courtesy of Farrel-Birmingham Co.

Fig. 3—A single geared rubber mill refiner, equipped for line shaft drive. The drive and connecting gear elements are enclosed in oil-tight, dust-proof guards and are bath lubricated. Journal bearings are served by sight feed oil cups.

render such a lubricant subject to rapid contamination by dust, dirt or other foreign matter, if exposed to their influence.

Contamination of this nature is, of course, decidedly objectionable as it materially reduces

those which are tightly encased. This, of course, means that more power must be consumed in their operation for the reason that heavy lubricants impose an appreciable "drag" or braking action as the teeth pass in and out of mesh.

Furthermore, the heavier the lubricant the greater will be the tendency for it to pick up and absorb dust, dirt or other abrasive solid matter. Instances have been noted in some mills where gears have even been allowed to operate in a mass of condensed dust and lubricant. Yet the operators could not figure out why their equipment rattled so much and why gear replacements were so frequently necessary. In such cases a tin oil pan, properly cut to fit around them would have served as an excellent partial means of protection.

It is thus with many older gear installations. Top guards may be installed to protect the operators, but below the teeth may be entirely open. Top guards will, of course, also prevent too light a lubricant from being thrown about promiscuously, but they are of relatively little value in keeping off all foreign matter. In such instances the art of the tinsmith is a valued asset, for it is remarkable how effective a gear housing can be made with sheet metal, a pair of shears, a soldering iron and a few rivets. Not always a beautiful object, but very effective in its protective ability.

Owing to the extent to which machinery may vary, it can be appreciated that gear lubrication could very easily involve all manner of difficulties. Necessarily the lubricating engineer must deal with equipment as it stands, hence he must develop the best practices possible to meet and serve the conditions existing. To a certain extent recommendations are possible for alteration in bearing design, gear and bearing protection against dust, preservation and reclamation of applied lubricants, etc., but to be effective this must actually be carried out by the mechanical organization of the plant, and it requires close attention and experimentation. Observation of the above remarks as to the lubricant itself, will be of value to all concerned, and if it is selected to meet conditions and applied as advised gear lubricating troubles will seldom be serious.

Oil Level Important

It is essential to remember where gears are bath lubricated that the level of the oil must be carefully watched. This will be especially true where heavier lubricants are used, and where there may be a comparatively wide range of operating temperatures, for one must remember that the development of "drag" or excessive internal friction may become a decided factor in the matter of power consumption.

As a rule where gears are bath lubricated it will be well to carry the oil level at such a height as to insure suitable dipping of the teeth of the lower element; or submergence of too much of the gear or pinion is not advisable and, as a general rule, unless comparatively fluid oils are used, it will not be necessary. The teeth will carry an adequate amount of oil up to those of the companion gear.

In the lubrication of rubber mill gears, as in the case of many other types of production machinery, it must be realized that gear lubrication will involve more than the mere prevention of wear or noise. There will be a direct tie-back to production.

In other words, whereas noise is nerve racking and wear will eventually necessitate replacement, back of all this is the development of detrimental operating conditions which may not only impair the quality of the product but may also increase power consumption. It is surprising how much power can be wasted as a result of neglect and lack of appreciation of the fact that gears are quite as accurately designed as any other machine parts. As a result their lubrication is of equal importance.

In view of the comparatively heavy bodied character of the lubricants usually employed for such service, these facts must be appreciated and the oil level especially must be studied in order that it may be maintained at just the right point on all installations.

There is one thought, however, which must not be overlooked. With heavier gear lubricants it will be possible to run with a somewhat lower level than where more fluid products are used. It is for this reason that reduction gear units are usually equipped with an external gauge glass to enable the operator to observe at all times just what level he is carrying.

MC,
C.